1-1-2016

Managing User Delay with a Focus on Pedestrian Operations

Christopher Sobie
Northern Arizona University

Edward Smaglik
Northern Arizona University

Anuj Sharma
Iowa State University, anujs@iastate.edu

See next page for additional authors

Abstract

Across the United States, walking trips are increasing. However, pedestrians still face significantly higher delays than motor vehicles at signalized intersections because of the traditional signal timing practices of prioritizing vehicular movements. This study explored methods to reduce pedestrian delay through the development of a pedestrian priority algorithm that selects an operational plan favorable to pedestrian service, provided a user-defined volume threshold has been met for the major street. This algorithm—along with several operational scenarios—was analyzed with Vissim with the use of software-in-the-loop simulation to determine the impact these strategies have on user delays. One of the operational scenarios examined was that of actuating a portion of the coordinated phase, or actuated–coordinated operation. Following a discussion on platoon dispersion and the application of it in the design of actuated–coordinated signal timing parameters, a sensitivity analysis was performed on vehicle extension timers to explore the impact that this coordinated movement parameter has on user delay. In the scenario analysis, it was shown that employing fully actuated (also known as free) operation—either with the designed algorithm or without—was an effective method of reducing pedestrian delay on the minor street while decreasing average intersection vehicle delay for the volumes used in the simulation. The vehicle extension sensitivity analysis showed that shortening the extension timer of an actuated–coordinated phase can reduce pedestrian delay on the minor street without increasing overall vehicle delay. This tool could be used by agencies during coordinated operation to prioritize pedestrians.

Authors

Christopher Sobie, Edward Smaglik, Anuj Sharma, Andrew Kading, Sirisha Kothuri, and Peter Koonce

Managing User Delay with a Focus on Pedestrian Operations

TRB Paper ID 16-1487

Word Count: 5496 + 6 * 250 = 6996 (not including references)

Christopher Sobie
Department of Civil Engineering, Construction Management, and Environmental Engineering
Northern Arizona University
ces327@nau.edu

Corresponding Author:
Edward Smaglik
Department of Civil Engineering, Construction Management, and Environmental Engineering
Northern Arizona University
Box 15600
Flagstaff, AZ 86011
Phone: (928) 523-1431
edward.smaglik@nau.edu

Anuj Sharma
Department of Civil Engineering
Iowa State University of Science and Technology
anujs@iastate.edu

Andrew Kading
Department of Civil and Environmental Engineering
Portland State University
Andrew.kading@pdx.edu

Sirisha Kothuri
Department of Civil and Environmental Engineering
Portland State University
skothuri@pdx.edu

Peter Koonce
City of Portland, Bureau of Transportation
Peter.koonce@portlandoregon.gov

ABSTRACT

Across the U.S, walking trips are increasing. However, pedestrians still face significantly higher delays than motor vehicles at signalized intersections due to traditional signal timing practices of prioritizing vehicular movements. This study explores pedestrian delay reduction methods via development of a pedestrian priority algorithm that selects an operational plan favorable to pedestrian service, provided a user defined volume threshold has been met for the major street. This algorithm, along with several operational scenarios, were analyzed with VISSIM using Software-In-The-Loop (SITL) simulation to determine the impact these strategies have on user delays. One of the operational scenarios examined was that of actuating a portion of the coordinated phase, or actuated-coordinated operation. Following a discussion on platoon dispersion and the application of it in the design of actuated-coordinated signal timing parameters, a sensitivity analysis was performed on vehicle extension timers to explore the impact that this coordinated movement parameter has on user delay. In the scenario analysis, it was shown that employing fully actuated (also known as Free) operation, either with the designed algorithm or without was an effective method of reducing minor street pedestrian delay while also decreasing average intersection vehicle delay for the volumes used in the simulation. The vehicle extension sensitivity analysis showed that shortening the extension timer of an actuated-coordinated phase can reduce the minor street pedestrian delay without increasing overall vehicle delay, which could be a tool used by agencies while in coordinated operation to prioritize pedestrians.

INTRODUCTION

Traffic signals in urban areas are locations where all modes converge – bicycles, pedestrians, autos, trucks and transit come together with limited time and space. The goal of signal timing at an intersection is to safely separate conflicting movements in time, while efficiently moving people. Signal timing directly affects the quality of our transportation system (*1*), and is often reflective of a region's transportation policy and goals, with these goals determining the priority by which users are served at an intersection. In the United States, traditional signal timing objectives have focused on encouraging through vehicle progression and/or minimizing vehicular delay and stops, which can sometimes lead to unnecessarily large delays for pedestrians and other modes.

A growing awareness of increased walking and cycling has increased focus on balancing the needs of all users at intersections. Traditional control strategies for pedestrians such as Leading Pedestrian Interval (LPI) and Exclusive Pedestrian Phase (EPP) have focused on safety improvements rather than efficiency. Delay reduction strategies targeted for pedestrians have been rather limited and are rarely implemented on a wide scale. As an example, the City of Portland has been implementing pedestrian focused signal timing at intersections since 2011. The strategies employed have included eliminating signal coordination by time of day, increasing permissive lengths, and reduced cycle lengths to reduce the delay for pedestrians, but these strategies are not responsive to traffic conditions using real-time data.

This paper proposes and analyzes an algorithm designed to prioritize pedestrian service under certain traffic conditions. The algorithm analyzes field data and changes the active operational strategy to match conditions in the field. The goal is to automatically select a strategy that matches the policy objective based on data that can be readily collected in the field with equipment commonly used by traffic signal practitioners.

The use of actuated operations on the coordinated phase is also considered as a method by which to reduce user delay for minor street pedestrian movements. Platoon dispersion is explored to assess the proper time to terminate a coordinated movement based on a platoon flow profile, thereby making time available for other movements without severely penalizing the coordinated movements. Data from the field is used to develop a VISSIM model and proposed signal timing strategies are examined using Software-in-the-Loop (SITL) simulation including a virtual Econolite ASC/3 traffic controller. Pedestrian and vehicular delay are measured and compared on a corridor running in coordination, free, and with the algorithm employed to select an alternate strategy based upon vehicle volume. Also, a sensitivity analysis is performed on gap timers to show the possible impacts of using platoon dispersion techniques to terminate a coordinated phase during actuated-coordinated operation.

BACKGROUND

Implementation of signal control strategies for pedestrians have been fairly limited and are typically focused on improving safety rather than addressing efficiency issues. Strategies such as the Leading Pedestrian Interval (LPI) and Exclusive Pedestrian Phase (EPP), are designed to reduce pedestrian vehicle conflicts. In a traditional LPI, pedestrians are provided with an exclusive walk signal for a few seconds prior to the onset of the parallel vehicular green indication. This scheme provides pedestrians greater visibility and allows them to establish themselves in the crosswalk and begin crossing before the vehicles can start their turning maneuvers. Some studies have reported reduced conflicts between pedestrians and turning vehicles due to LPI implementation (*2,3)*. One study also reported a reduction in pedestrians yielding the right of way to turning vehicles (*4*). In addition to actual safety improvements, LPI's may also improve perceptions of safety. However, due to the lost time for vehicles during LPI, vehicular delays may increase, which should be assessed prior to implementation (*5*). An EPP, also known as a Barnes Dance or a Pedestrian Scramble, is a type of phasing in which pedestrians are permitted exclusive use of the intersection including lateral and diagonal crossings while all vehicular traffic is stopped. The Walk signal for all crosswalks is displayed simultaneously. Implementation of an EPP increases delay for all users, and several studies have documented increased pedestrian non-compliance due to this increased delay (*6,7*).

Efficiency focused strategies for pedestrians include lowering cycle lengths, increasing the permissive period and changing the mode of signal operation from coordinated to free. Many studies have shown the benefits of reduced cycle length in terms of lower pedestrian delays *(8,9,10*). One study showed statistically significantly lower pedestrian delays as a result of increasing the permissive period for pedestrians (*11*), however the study did not report the effects on other users. Other strategies for reducing pedestrian delays include operating the signal controller in a free mode, when vehicle volumes are low (*10*). However, the decision to operate the signal controller in free depends on the managing agency's policy and this not readily acceptable for many agencies. One method to free up a little bit of time in the cycle when running in coordination is to actuate the coordinated phase, which allows the coordinated phases to gap out once the main platoon has been served. Day et al. have shown that actuating a portion of the coordinated phase can improve v/c ratios and decrease split failures for the minor street movements (*12*), however, the impacts on pedestrian delay were not quantified in that work.

Platoons are introduced in a signalized arterial system by the presence of upstream traffic signals. During queue clearance time, an upstream signal discharges at saturation flow during the queue clearance phase and this tightly packed stream of vehicles propagating downstream is termed as platoon. One of the main objectives of signal coordination is to allow this platoon to traverse through a series of tightly spaced intersection with minimal stops, and this can drive very long green times on the coordinated movements. This is often implemented in signal timing tools by using techniques such as bandwidth optimization (*13,14*). The platoon of tightly packed vehicles starts dispersing as it propagates towards the downstream signal. The duration of green on a coordinated movement determines how much of the platoon will be allowed through on any given indication. Ending a coordinated green early, either through policy, vehicle extension value manipulation, or actuation of the coordinated phase is another method by which minor phase pedestrian service could be prioritized.

The research profiled in this paper builds upon the previous work in multiple ways. First, the algorithm developed is designed to prioritize minor phase pedestrian service under certain volume conditions using a form of traffic responsive operation. Once the user defined volume threshold has been met, any of the efficiency strategies listed above can be implemented until the volume conditions are no longer met. In addition to Free operation, another efficiency strategy is that of actuating the coordinated movement. A discussion on Platoon Dispersion suggests guidance for selecting an allowable headway, and thereby selecting settings for actuated-coordinated operation, for platoon continuance based upon operational characteristics. Next, using SITL, the efficiency impacts on all users of an intersection with the implemented algorithm are documented to provide application guidance. Lastly, a sensitivity analysis is performed on main street vehicle extension values to show the user delay impact of terminating a coordinated phase early based upon platoon dispersion principles.

PLATOON DISPERSION MODELING

Platoon dispersion, as discussed earlier, has been modeled by several constructs (*15,1617,18, 19*). One of the most commonly used techniques to model platoon dispersion is Robertson's model that was incorporated into TRANSYT signal timing software (*15*). Robertson's model estimates downstream flow in different time intervals using the upstream flow profile as shown in Equation 1.

$$q'_{(i+t)} = F.q_i + (1-F).q'_{(i+T-1)} \qquad \text{Equation 1}$$

Where, $F = \frac{1}{1+\alpha.\beta.T}$

In Equation 1, q_i is the flow in the i^{th} time interval of the upstream platoon, q'_i is the flow in the i^{th} time interval of the predicted platoon at the downstream signal, α is the platoon dispersion factor, β is the travel time factor, T is average travel time between upstream signal to the downstream signal over which the platoon disperses and F is a smoothing factor. Platoon dispersion characteristics depend on several factors such as signal spacing, signal visibility, roadway gradient, and driver characteristics. These changes have been captured by calibrating the values of alpha and beta parameters (*20,21, 22*). Figure 1 a-c shows an example plot of a platoon dispersing over a corridor. Figure 1c shows a platoon at location 0 which corresponds to queued vehicles discharging at saturation flow rate, each having a headway of 1 sec, assuming a 2 lane roadway. The height of the bar corresponds to number of vehicles observed in a 4 second interval. So, for Platoon 0 we observe 4 vehicles for each 4 second interval. The annotation at the top of the bar represents time headway observed for vehicles in a given time interval. For a Platoon at 0 seconds all the intervals see vehicles appearing with a headway of 1 sec. The line represents the percentage of platoon remaining at a given point in time. The platoon is dispersed using Robertson's model assuming an $\alpha.\beta$ value of 0.17. This value was observed by Day et. al. (*22*) and is used here for the purpose of illustration. The profile of the platoon is dispersed significantly after traveling for 10 seconds. The platoon distribution is right skewed with a long tail. At this point, the first 10 vehicles, approximately 83% of the platoon (annotated by *a* in the Figure 1b), need 20 seconds of green time to be served, nearly double the time required by the platoon at time 0. The last two vehicles can extend the phase for more than another 8 seconds. It can also be seen that towards the end of the platoon, the headway increases exponentially (from H: 3.4s at time 48 sec to H of 13.5 s at time 60 sec). This implies that marginal cost levied on opposing movements, including pedestrians, for serving each additional platoon vehicle rises exponentially towards the tail of the platoon. The Platoon at 20 seconds further exacerbates these effects. It can be seen that it take almost 30 seconds to serve the first 10 vehicles (annotated by *b* in the Figure 1a) and the last two vehicles can take more than 40 seconds.

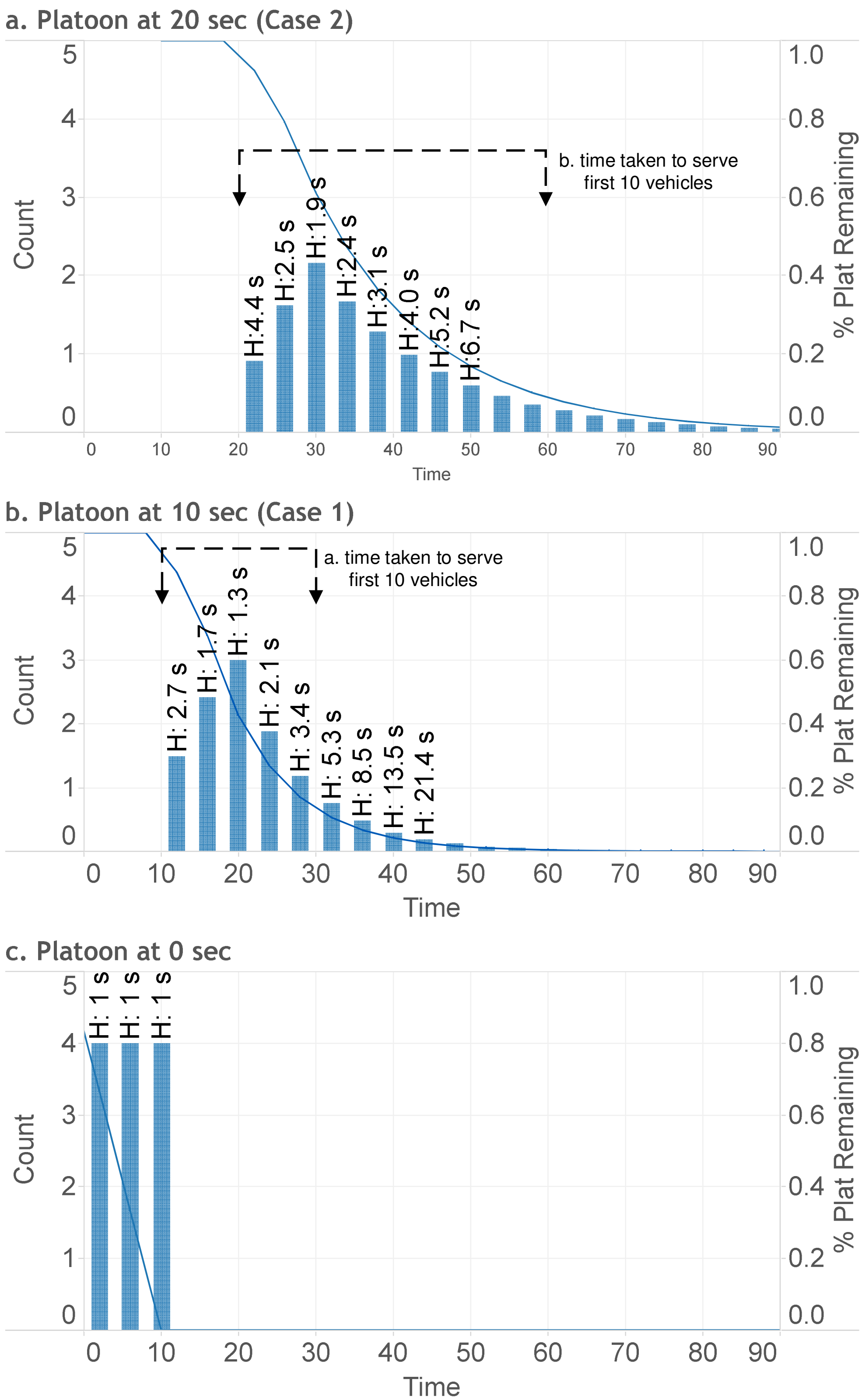


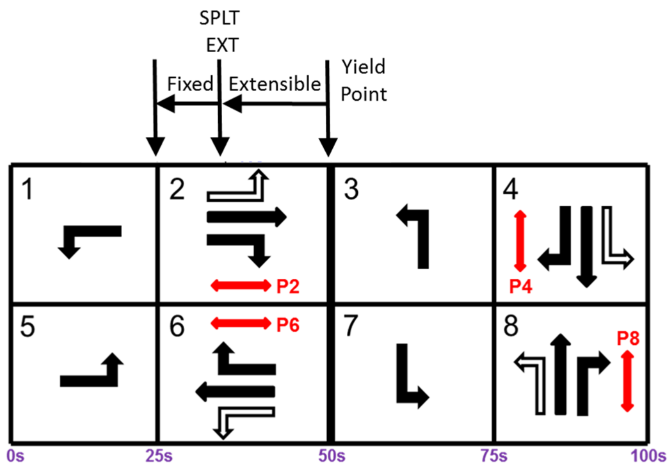
Figure 1 Robertson's platoon dispersion diagram for locations 10 sec and 20 sec away from the point of origin of the platoon assuming α.β value of 0.17.

Some signal optimization software, such as Synchro, use a cost function of stops and delays as the basis for signal timing optimization. The weight used to quantify the tradeoff between stops and delays constrain the number of vehicles in the platoon that would be cut off at the max-out time. Other signal optimization tools make use of interference minimization techniques or green band maximization techniques for obtaining the signal timing. These tools can explicitly ascertain the number of vehicles that will served for a given platoon. The signal timing developed from optimization software are then implemented in the field either using non-actuated or actuated coordinated phases. With non-actuated coordinated phases, it is assumed that the platoon always arrives and ends at the same time, has a constant length and thus the green duration of the coordinated phase is fixed to serve the fixed platoon in each cycle.

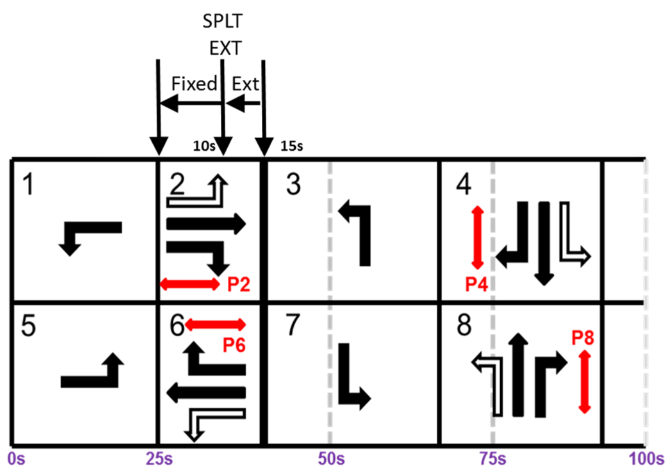
In the real-world, the size of the platoon can vary among cycles due to variability of flow rate from the upstream signal. While the arrival time of the platoon may vary due to midblock influences, pedestrian crossings, or transit stops, for the purposes of this work we will presume the arrival time of the platoon is relatively consistent. To account for any stochastic variability in platoon lengths, the coordinated phase can be set in actuated-coordinated mode. In this case, for the coordinated phase a fixed period of green time is assigned to serve most of the platoon and following that an extensible period is assigned where the phase is allowed to gap out if the platoon is not received as predicted.

Figure 2 illustrates actuated coordinated operation within the ring barrier diagram (RBD) using the terminology employed by the field controller used in the subsequent sections of this research. In this example, Phases 2 and 6 are the coordinated phases, and there is a 100 second cycle length equally divided between all phases. Figure 2a shows the base RBD with two of the three actuated-coordinated mode parameters identified above the coordinated movements (fixed and extensible periods). In this controller (Econolite ASC/3), the value SPLT EXT (Split Extension) identifies the length of time within the full split that is extensible (this is calculated back from the yield point). After the fixed period has passed, the coordinated phases are only held green for active vehicles (extensible period). In this example, the SPLT EXT value is set to 15s, creating a 15s extensible period. The termination of the extensible period can be made more or less aggressive through selection of the extension timer value (the third parameter for actuated-coordinated operation) and by using (or not using) certain features such as simultaneous gap out or lane-by-lane detection (*23,24*).

In Figure 2b, the termination of the platoon on the coordinated phase has resulted in gap-out termination 5s into the extensible period (dashed lines indicate where phases would have terminated had they timed to their original force off points in Figure 2a). This coordinated phase terminated early because either the entire platoon was served during the fixed portion of the coordinated phase, or the platoon extended past the fixed phase and the headway exceeded a critical maximum headway programmed to ensure most of the platoon is served. The time remaining from this early termination can be used to serve other users, including minor phase pedestrians, earlier, reducing user delay. It should be noted that for operations to function as described, the Force-Off setting would need to be ‘floating.’



a) Base ring barrier diagram with several actuated-coordinated parameters



b) Gap out termination 5s into extensible period allows for early termination

Figure 2 Ring Barrier Diagram for Actuated-Coordinated Operation

The maximum allowable headway is directly related to the extension timer for the coordinated phase, and along with the duration of the fixed period and the extensible period, controls how much of the platoon is served, and therefore how much additional time can be made available for other users. Actuated-coordinated operation as described above is one of the algorithm driven operational scenarios evaluated with simulation in this paper, and while settings for all three parameters of actuated coordinated operation are not explored, a sensitivity analysis is performed on gap extension timer values to determine their impact on user delay.

PEDESTRIAN PRIORITY ALGORITHM

The use of the existing traffic signal controller to implement signal timing plans that prioritize pedestrians is considered advantageous from a maintenance standpoint. For this reason, the algorithm developed in this work uses an onboard logic processor within a traffic controller to allow the controller to switch into a pedestrian priority operational plan (PPOP) based upon volume over a specified time interval (Econolite's ASC/3 controller was used in this work). The following pseudo-code generically presents the algorithm.

```
IF OPERATIONAL PLAN = X
        AND VEHICULAR VOLUME < THRESHOLD during last T minutes
        THEN INITIATE PEDESTRIAN PRIORITY OPERATIONAL PLAN
ELSE CONTINUE OPERATIONAL PLAN X
```

The logic processor is only able to test and modify certain parameters within the controller. For monitoring volumes, this controller can make decisions based upon NTCIP stored vehicle volumes. Since there is a limit of 204.7 seconds per NTCIP log period, a series of delays and logic flags are used to extend the duration of time monitored (*T* in the above pseudocode) to a preferred amount of time. The desired threshold for volume is dependent upon characteristics at the intersections in question. Prior work by Kothuri showed that pedestrian responsive strategies may be most applicable during coordination, when major street vehicles volumes are moderate ($0.5 < v/c < 0.8$) and minor street pedestrian volumes are low or moderate (*10*). Volumes are monitored for the movements selected by the user (typically the through movements for the major approaches), and the controller will switch into the PPOP if the volumes are below the target threshold for the desired volume collection period. Figure 3 is a flowchart showing the general steps of the algorithm. The thresholds for entering and exiting the PPOP (those implied by 'Monitoring Detector Volumes for t_1 and t_2 minutes) should be set by examining the vehicle volumes (or V/C ratios) and determining when, generally during the day, the operator would prefer the PPOP be operational.

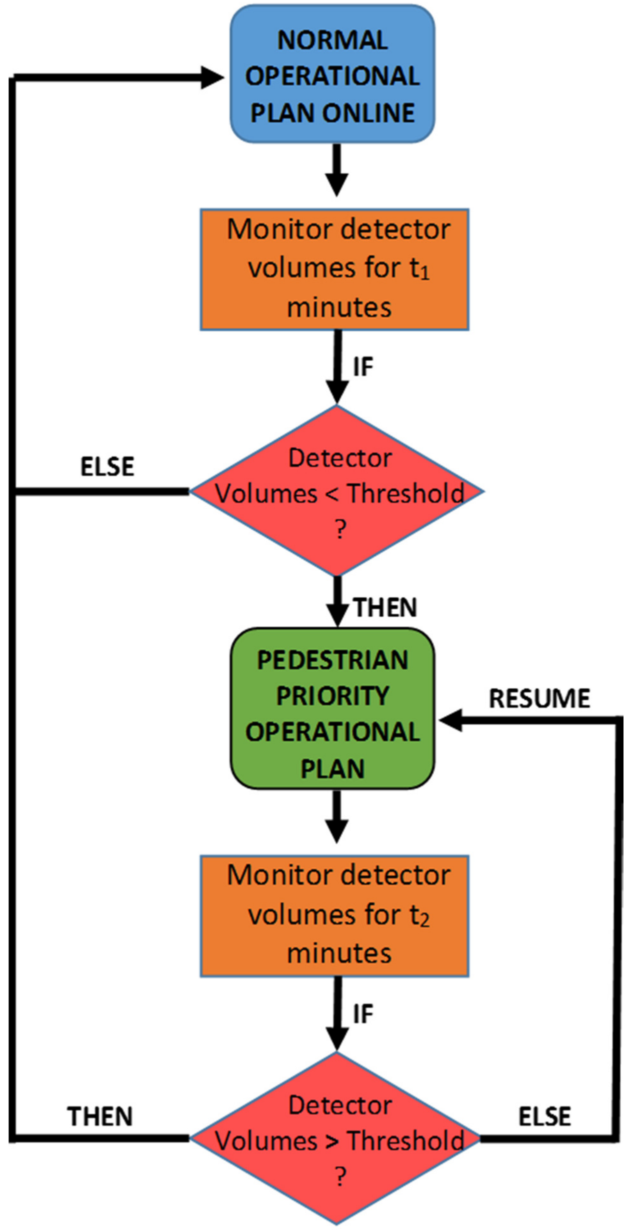


Figure 3 Pedestrian Priority Algorithm Flowchart

Within the logic processor of the controller, the Operational Plan can be selected based upon the outcome of a test. The Operational plan is used to assign the timing plan (MIN & MAX greens, VEH EXT, etc.) and coordination plan along with other associated options. Therefore, within the logic processor the user can define which Operational Plan to switch to when vehicle volumes are below the desired threshold. This is identified as the Pedestrian Priority Operational Plan (PPOP) in Figure 3. Depending on user preferences, the PPOP could shorten the cycle length, change the permissive periods, or adjust coordination settings to reduce the delay experienced by minor phase pedestrians. While in the PPOP, the logic processor continues to monitor volume to either keep the PPOP in action, or change back to the Normal plan. The amount of time between possible operational plan changes is user definable to avoid hopping back and forth between plans too quickly. It must be noted that when transferring between the normal operational plan and the PPOP the transitional impact on signal operation is dependent upon the chosen strategy. If the user chooses to transition to an actuated coordinated PPOP with the same splits, offset, and cycle length, there is no transitional impact. However, if the user chooses to drop into 'FREE' operation, there is a distinct impact on signal operation as return to coordination is not instantaneous. The following sections will evaluate the impact that the employment of this algorithm has on user delay.

SIMULATION MODEL DEVELOPMENT

To evaluate the PPOP, a simulation model was used to vary traffic parameters and observe their impact on the PPOP, and quantify performance differences between that mode of operation and others (actuated-coordinated, coordinated, and free). VISSIM was chosen at the tool for this simulation because of its general flexibility, along with its ability to use a field controller, Econolite's ASC/3 in this case, to drive the traffic control in the simulation. This allows researchers to test real-world traffic algorithms in a simulation environment (SITL), a tool which has proved to be successful (*25,26,27,28*).

Three intersections were chosen for simulation along SE Division Street in Portland, Oregon, a major east-west arterial corridor on the east side of the city carrying approximately 18,000 vehicles per day. The intersections chosen were SE 119th Avenue, SE 122nd Avenue and SE 130th Avenue along the corridor as shown in **Figure 4**. Along this stretch, SE Division Street has two lanes in each direction, with additional turn lanes at intersections. This stretch of the corridor was chosen because the conditions observed along this corridor are suitable for implementation of such a strategy (the field implementation of this will be profiled in future work). Second, the intersection of SE Division St. and 122nd Ave. was identified as a high crash location by the City of Portland and as such the possibility of implementing strategies to improve conditions for pedestrians is consistent with city policies. Lastly, the intersection of SE 122nd and Division has been previously equipped as a test intersection, with redundant detection by multiple technologies on all approaches. This, combined with the use of an event based data logger designed for the Northwest Signal Voyage control platform developed for another project the authors are engaged in, allows for powerful data collection at this location.

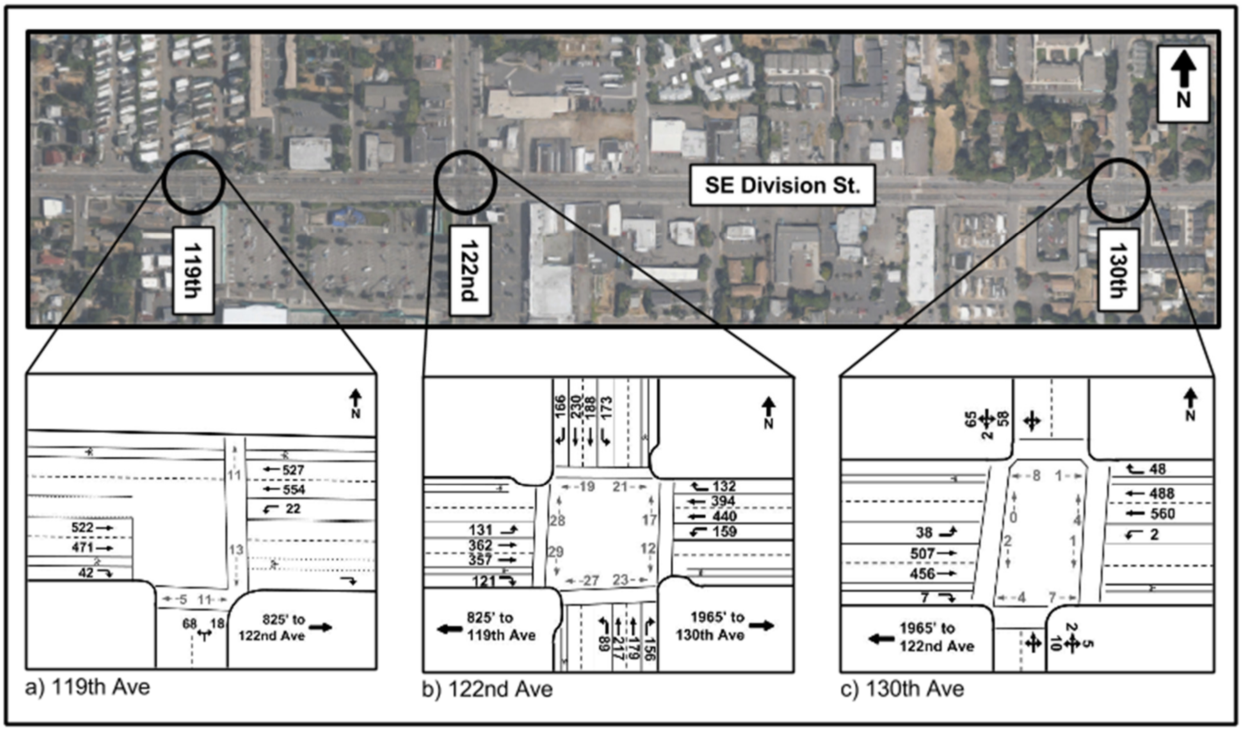


Figure 4 SE Division St and 122nd Ave Lane Configuration, Traffic, and Pedestrian volumes

The data inputs for model development were gathered from a variety of sources. The lane configuration and network geometry was derived from Google Earth satellite imagery and verified in the field. The background image native to VISSIM, from Bing maps, was use for network coding and development. The width of all lanes including turn lanes was measured and ranged between 10-12 ft. All pedestrian crosswalk widths are as in the field. Speeds were obtained from posted speed limit signs on the respective facilities. Traffic volumes and turning movements were obtained from manual counts using prerecorded video data at the three intersections. The traffic compositions on the major and minor streets were roughly 95% cars and 5% heavy vehicles, with values compiled from the video data. Signal timings were developed for the corridor using Synchro 9.0 and manually counted vehicle data collected during June, 2015. After discussions with PBOT, the design hour of 11:00 AM – 12:00 PM was selected, as it was believed to be the most desirable combination of pedestrian and vehicular traffic discussed earlier. These timings, along with the algorithm discussed earlier, were implement using the ASC/3 SITL controller. While this model and its signal timing were developed and calibrated with real world data, this model has not been validated to actual field conditions (*29,30*). All statistical comparisons that come from the results of these simulations are internal comparisons; that is they are compared between simulated models.

EXPERIMENTAL DESIGN

The simulation in this work was undertaken with a dual purpose. First, the authors desired to see the impact of implementing various PPOPs on user delay, and second, to observe the hypothetical impacts of terminating an actuated coordinated phase early through selection of extension timer values.

Comparison of Algorithm and PPOPs

To test the impacts of a PPOP employed with the traffic responsive algorithm, the first step was to develop a base timing plan to which the other strategies would be compared. Data for all comparisons was collected from operations at SE 122nd / SE Division, the same location at which all operational changes were made. Pertinent characteristics of the base timing plan are:

- Coordination along SE Division St with a cycle length of 110s. The exact plan was selected through Synchro 9.0 analysis using a comparison of the Synchro Performance Index and natural cycle lengths observed in the field during free operation (during the same time period)
- Detection within the simulation is reduced from actual field detection, but ample enough to drive all strategies.
- SE 122nd / SE Division Characteristics
    - Stop detection present on all left turn movements
    - Advance detection present on all through movements
    - Ped service for phases 2/6 is coordinated rest in walk
    - Ped service for phases 4/8 is actuated
    - Pedestrian volumes on 2/6 are as shown in **Figure 4** while pedestrian volumes on 4/8 were selected to actuate a ped call roughly every four cycles. This was done to approximate low to moderate side street ped activity.

The compared scenarios are the following:

1. Coordinated-Base
2. Actuated-Coordinated using the responsive algorithm (Coordinated-Base when PPOP not active)
    a. SPLT EXT values of 15s were used for each ring (this was all that was available after accounting for Ped Recall). Note: Ped Recall used with actuated-coordinated operation does not rest in walk. It serves Walk and Ped Clear as it would in an actuated setting
3. Free using the responsive algorithm (Coordinated-Base when PPOP not active)
4. Free

Each simulation was 75 minutes long with 15 minutes for network population and 60 minutes for data collection. In order to activate the traffic responsive algorithm, the volumes on the E/W links were varied per the following:

- 15 minutes at high volume (v/c value 0.20 greater than observed in field)
- 30 minutes at low volume (v/c value 0.20 less than observed in the field)
- 30 minutes at high volume (v/c value 0.20 greater than observed in the field)

In scenarios 2 and 3 above, the PPOP was active for roughly 30 minutes of the monitored 60 minute period. Each scenarios was run 10 times with different random seed values for each simulation (the same 10 random seeds were used across each scenario).

Sensitivity Analysis of Vehicle Extension Timers

Selection of a maximum allowable headway based upon operational objectives would result in using actuated coordinated operation with values for the extensible period and extension timer chosen through a mathematical process. To emulate the impact that this type of operation may have user delay, using the simulation network developed in this work a sensitivity analysis was undertaken on the vehicle extension timer value to observe the change in user delay with more (or less) aggressive maximum allowable headway settings. For this comparison, ped recall with no rest in walk was used on phases 2/6 (ped service on 4/8 was actuated) and extension timers on 2/6 were varied between 3.5s (base case) and 0.0s in ½ second increments (given that Division St. is a 35 mph roadway, dilemma zone impacts were not considered in this analysis, as dilemma zone is typically not a major concern with operating speeds under 45 mph). Pedestrian volumes were the same as in the scenario comparison; vehicle volumes were as collected in the field and were not varied during the simulation period.

RESULTS

Table 1 and **Table 2** show the comparative results of the simulation in absolute and percentage values, with the scenario comparison in **Table 1**a and **Table 2**a and the extension timer comparison in **Table 1**b and **Table 2**b. For the scenario comparison, the coordinated scenario is the base case and all comparisons are relative to the base. It was observed that either scenario including free operation significantly decreased average vehicle delay, while the scenario with actuated-coordinated operation had no significant difference. This is not surprising as it is common for coordinated operation to result in higher average vehicle delay for all users than other strategies. Travel times NB and SB were significantly reduced with any free operation while travel times EB and WB increased with any free operation, significantly in all cases except for free with algorithm. From a pedestrian standpoint, delay increases significantly on phases 2 and 6, but this is to be expected as the base case serves peds with rest in Walk (Flashing Don't Walk terminates with green termination) while the other strategies serve pedestrians on 2 and 6 with a defined walk period (7s) followed by ped clear, with the pedestrian indication dwelling in solid Don't Walk until the next Walk indication. For pedestrians on phases 4 and 8, all strategies resulted in a decrease in pedestrian delay, with the Free strategy seeing a significant difference (32.7% decrease in delay from the base case). This, along with the fact that both Free strategies show a significant decrease in average vehicle delay indicate that Free may be a valid option to reduce minor phase pedestrian delay without negatively impacting vehicular delay. The actuated-coordinated strategy reduced ped delay on phases 4 and 8 by 3.3%, albeit not significantly, and left average vehicle delay essentially unchanged (0.7% increase). With more aggressive settings, the actuated-coordinated strategy may yield significant differences.

Table 1: Simulation Results, absolute values

Scenario	Avg. Veh Delay (s)	Avg. Ped Delay 2/6 (s)	Avg. Ped Delay 4/8 (s)	Avg. TT (s) (EB)	Avg. TT (s) (WB)	Avg. TT (s) (NB)	Avg. TT (s) (SB)
Coordinated (Base)	26.55	25.43	44.95	100.71	90.61	94.79	90.77
Actuated Coordinated	26.73	36.45*	43.45	101.98	90.99	94.81	91.28
Free with Algorithm	25.11*	28.44*	41.28	102.25	99.93*	87.69*	84.39*
Free	22.81*	32.87*	30.25*	104.25*	107.62*	77.73*	74.50*

* Statistically significant at 95% confidence level. For all scenarios, ped call every 4th cycle on P4/8.

a) Scenario comparison

Vehicle Extension Timer (s)	Avg. Overall Delay (s)	Avg. Veh Delay (s)	Avg. Ped Delay 2/6 (s)	Avg. Ped Delay 4/8 (s)	Avg. TT (s) (EB)	Avg. TT (s) (WB)	Avg. TT (s) (NB)	Avg. TT (s) (SB)
0	26.74	26.14	48.07	38.33	104.89*	89.76	94.69	90.28
0.5	26.73	26.14	48.08	38.33	104.89*	89.76	94.70	90.26
1.0	26.73	26.91	48.14	38.44	104.86*	89.64	94.63	90.37
1.5	26.65	26.04	48.08	38.86	104.13*	89.53	94.70	90.33
2.0	26.70	26.07	48.27	39.59	103.50*	89.44	94.84	90.68
2.5	26.75	26.11	48.60	41.66	102.92*	89.58	95.09	90.57
3.0	26.68	26.04	48.64	42.57	101.98	89.19	95.23	90.68
3.5 (Base)	26.57	25.94	48.49	42.19	101.08	89.16	94.99	90.51

* Statistically significant at 95% confidence level. For all scenarios, ped call every 4th cycle on P4/8.

b) Extension timer value sensitivity analysis

Table 2: Simulation Results, percentage values

Scenario	Avg. Veh Delay	Avg. Ped Delay 2/6	Avg. Ped Delay 4/8	Avg. TT (EB)	Avg. TT (WB)	Avg. TT (NB)	Avg. TT (SB)
Actuated Coordinated	0.7	43.3	-3.3	1.3	0.4	0.0	0.6
Free with Algorithm	-5.4	11.8	-8.2	1.5	10.3	-7.5	-7.0
Free	-14.1	29.3	-32.7	3.5	18.8	-18.0	-17.9

a) Scenario comparison

Vehicle Extension Timer	Avg. Overall Delay	Avg. Veh Delay	Avg. Ped Delay 2/6	Avg. Ped Delay 4/8	Avg. TT (EB)	Avg. TT (WB)	Avg. TT (NB)	Avg. TT (SB)
0	0.6%	0.8%	-0.9%	-9.1%	3.8%	0.7%	-0.3%	-0.3%
0.5	0.6%	0.8%	-0.8%	-9.1%	3.8%	0.7%	-0.3%	-0.3%
1.0	0.6%	3.7%	-0.7%	-8.9%	3.7%	0.5%	-0.4%	-0.2%
1.5	0.3%	0.4%	-0.8%	-7.9%	3.0%	0.4%	-0.3%	-0.2%
2.0	0.5%	0.5%	-0.5%	-6.2%	2.4%	0.3%	-0.2%	0.2%
2.5	0.7%	0.7%	0.2%	-1.3%	1.8%	0.5%	0.1%	0.1%
3.0	0.4%	0.4%	0.3%	0.9%	0.9%	0.0%	0.3%	0.2%

b) Extension timer value sensitivity analysis

For the extension timer comparison, the base case was the scenario with vehicle extension timer value of 3.5s. As expected we see an increase in travel times on EB and WB, significantly on EB with extension timer values of 2.5s or lower (0.9% - 3.8% increase compared to base case). Travel times on NB and SB were roughly unchanged. Average vehicle delay across the intersection did increase when the extension timer value dropped, though not significantly. This is not surprising as lower extension timer values on the coordinated phase will increase delay on that phase, and with the large vehicle volumes, this can increase the overall delay. For pedestrians, while there were no significant differences, pedestrian delay on phases 4 and 8 dropped almost four seconds from the base case to the 0.0s extension value timer (decrease of 9.1%). This, combined with an average vehicle delay increase of only 0.20s (0.6%) between these strategies, shows that manipulation of phase termination through platoon dispersion techniques may be a promising method to reduce minor phase pedestrian delays with negligible impacts on vehicle delays.

CONCLUSION

The objective of this paper was to explore alternate signal timing methods with the intent of placing a priority on serving minor phase pedestrians with lesser delay than typically experienced with status quo signal timing. To accomplish this, a traffic responsive algorithm was developed to change the operational plan of a traffic signal to a plan which is favorable to pedestrians when vehicular volumes drop below a certain threshold. This algorithm, along with several operational scenarios, were analyzed with VISSIM SITL simulation to determine their impact on user delays. In addition, following a discussion on platoon dispersion and the application of it in the design of actuated-coordinated signal timing parameters, a sensitivity analysis was performed on vehicle extension timers to explore the impact that this coordinated movement parameter has on user delay. In the scenario analysis, employing Free operation, either with the designed algorithm or without was an effective method of reducing minor street pedestrian delay while also decreasing average intersection vehicle delay. Compared to the base coordinated scenario, a 5 – 14% reduction in average vehicle delays was observed with an 8 – 33% reduction in average pedestrian delays on the minor phase were observed. The vehicle extension sensitivity analysis showed that shortening the extension timer of an actuated-coordinated phase can reduce the minor street pedestrian delay without increasing overall vehicle delay. Percent reductions for the minor street pedestrian phase varied from 1.3 to 9.1%, with a reduction in the vehicle extension timer from the base case of 3.5s to 0.0s.

This research has just scratched the surface on several of these topics. Further sensitivity analyses could be conducted on other actuated-coordinated settings, namely the duration of the extensible period. In addition, varying the volume on the different movements within the model may provide insight as to under what conditions a specific pedestrian priority operational plan may perform best. Lastly, in this analysis, the cross street volumes were fairly close to those of the major street. It is expected that analysis of a location with larger difference between these volumes would result in greater reductions in pedestrian delays. Even without delving into these issues, this paper has effectively shown several methods that can be employed immediately to reduce minor phase pedestrian delay without negatively impacting vehicular delay.

ACKNOWLEDGMENT

The authors gratefully acknowledge funding support from the National Institute for Transportation and Communities, at Portland State University. The authors would also like to acknowledge the assistance provided by Paul Zebell and Willie Rotich from the City of Portland.

REFERENCES

1 Koonce, P., Rodegerdts, L., Lee, K., Quayle, S., Beaird, S., Braud, C., Bonneson, J., Tarnoff, P., Urbanik, T. Traffic Signal Timing Manual. U. S. Department of Transportation, Federal Highway Administration, 2008. Accessed at http://ops.fhwa.dot.gov/publications/fhwahop08024/fhwa_hop_08_024.pdf

2 Van Houten, R., R. A. Retting, C. M. Farmer, and J. Van Houten. Field Evaluation of a Leading Pedestrian Interval Signal Phase at Three Urban Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1734, Transportation Research Board of the National Academies, Washington, D.C., 2000, pp. 86–92.

3 Turner, P. Making Crosswalks Safer for Pedestrians. Project Report, *Center for Urban Transportation Research*, University of South Florida, Tampa, 2000.

4 Fayish, A. C. and F. Goss. Safety Effectiveness of Leading Pedestrian Intervals Evaluated by a Before-After Study with Comparison Groups. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2198, Transportation Research Board of the National Academies, Washington, D.C., 2010, pp. 15-22.

5 Saneinejad, S., and Lo, J. Leading Pedestrian Interval and Implantation Guidelines. In *Proceedings of the 94th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington D.C., 2015.

6 Bechtel, A., K. MacLeod, and D. Ragland. Pedestrian Scramble Signal in Chinatown Neighborhood of Oakland, California: An Evaluation. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1878, Transportation Research Board of the National Academies, Washington, D.C., 2004, pp. 19–26.

7 Kattan, L., Acharjee, S. and R. Tay. Pedestrian Scramble Operations. Pilot Study in Calgary, Alberta, Canada. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 2140, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 79-84.

8 Noland, R. Pedestrian Travel Times and Motor Vehicle Traffic Signals. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1553, Transportation Research Board of the National Academies, Washington DC, 1996, pp. 28-33.

9 Ishaque, M. M. Policies for Pedestrian Access: A Multi-Modal Tradeoff Analysis Using Micro-Simulation Techniques. PhD dissertation. University of London, 2006.

10 Kothuri, S., Koonce, P., Monsere, C., and T. Reynolds. Exploring Thresholds for Timing Strategies on a Pedestrian Active Corridor. In *Proceedings of the 94th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington DC, 2015.

11 Kothuri, S., Reynolds, T., Monsere, C. and P. Koonce. Testing Strategies to Reduce Pedestrian Delay at Signalized Intersections: A Pilot Study in Portland, Oregon. *In Proceedings of the 92nd Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington DC, January 13-17, 2013.

12 Day, C. M., Smaglik, E.J., Bullock, D.M., and J. R. Sturdevant. Quantitative Evaluation of Fully Actuated Versus Nonactuated Coordinated Phases. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2080, Transportation Research Board of the National Academies, Washington, D. C., 2008, pp. 8-21.

13 Petterman, J. L. Timing Progressive Signal Systems. In *Traffic Engineering*, Vol. 29, 1947, pp. 194–199.

14 Petterman, J. L. Timing Progressive Signal Systems—Part II. *Traffic Engineering*, Vol. 29, 1947, pp. 242–249.

15 Robertson, D. I. “TRANSYT” Method for Area Traffic Control. In *Traffic Engineering and Control*, Vol. 11, No. 6, 1969, pp. 276–281.

16 Robertson, D. I. Transyt: A Traffic Network Study Tool. Report No. LR 253. Road Research Laboratory, Crowthorne, Berkshire, United Kingdom, 1969.

17 Shoufeng L, and Ximin L, “Platoon dispersion prediction under the condition of adjacent cycle traffic flow overlapping based on support vector regression”, in Editor (Ed.), *Institute of Electrical and Electronic Engineers Inc*., 2007, edn., pp. 918-921.

18 Grace, M. J., and R. B. Potts. A Theory of the Diffusion of Traffic Platoons*. Operations Research*, Vol. 12, No. 2, 1964, pp. 255–275.

19 Seddon, P. A. Another Look at Platoon Dispersion: 1. The Kinematic Wave Theory. *Traffic Engineering and Control*, Vol. 19, 1971, pp. 332–336.

20 Yu, L. & Van Aerde, M. Implementing TRANSYT’s Macroscopic Platoon Dispersion in Microscopic Traffic Simulation Models. In *Proceedings of the 74th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington, D.C., 1995.

21 Yu, L.. “Calibration of platoon dispersion parameters on the basis of link travel time statistics.” In *Transportation Research Record* : *Journal of the Transportation Research Board*, No.1194, Transportation Research Board of the National Academies, Washington DC, 2000.

22 Day,C. M., and Bullock, D. M. Calibration of Platoon Dispersion Model with High-Resolution Signal Event Data. In *Transportation Research Record*, *Journal of the Transportation Research Board*, No2311, Transportation Research Board of the National Academies, 2012, pp16-28.

23 Sharma, A., Bullock, D. M., Peeta, S. Recasting Dilemma Zone Design as a Marginal Cost-Benefit Problem. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2035, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 88-96.

24 Smaglik, E. J., Bullock, D. M., Sturdevant, J. R., Urbanik II, T. Implementation of Lane-by-Lane Detection at Actuated Controlled Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2035, Transportation Research Board of the National Academies, Washington, D.C., 2007, pp. 81-87.

25 Khoshmagham, S., Feng, Y., Zamanipour, M., Head, L.K. Travel Time Observation in Privacy Ensured Connected Vehicle Environment Using Partial Vehicle Trajectories and Extended Tardity. In *Proceedings of the 94th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington D.C., 2015.

26 Zlatkovic, M., Stevanovic, A., Assessment of Impacts of Increased Train Frequency and Predictive Transit Priority on a LRT Corridor in Salt Lake City. In *Proceedings of the 93rd Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington D.C., 2014.

27 Day, C. M., Bullock, D. M. Design Guidelines and Conditions That Warrant Deployment of Fully Actuated Coordination. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2439, Transportation Research Board of the National Academies, Washington, D.C., 2014, pp. 1-11.

28 Abbas, M. M., Mladenovic, M. N., Ganta, S., Kasaraneni, Y., McGhee, C. C. Development and Use of Critical Functional Requirements for Controller Upgrade Decisions. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2355, Transportation Research Board of the National Academies, Washington, D.C., 2013, pp. 83-92.

29 Smaglik, E. J., Savolainen, P. T., Steele, R. C., DiBiasi, J. E. Delay Analysis of a Traffic Signal Phase Termination Algorithm Using Computer Simulation. In *Proceedings of the 90th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington D.C., 2011.

30 Smaglik, E. J., Bullock, D. M., Urbanik II, T. Bench Implementation of Restricted-Flow Bottleneck Identification and Flow-Based Phase Termination. In *Proceedings of the 87th Annual Meeting of the Transportation Research Board*, Transportation Research Board of the National Academies, Washington D.C., 2008.